(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 078 105**
A2

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: 82304926.7

(22) Date of filing: 17.09.82

(51) Int. Cl.³: H 01 J 61/82

(30) Priority: 28.10.81 GB 8132443

(43) Date of publication of application:
04.05.83 Bulletin 83/18

(84) Designated Contracting States:
DE FR GB NL

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(54) **Improvements in or relating to high pressure sodium lamps.**

(57) The invention provides an improved high pressure sodium lamp of nominally 70 watt rating operating at a lamp voltage V of substantially 70 - 130 volts in which for satisfactory life, efficacy and colour, for an arc tube of internal diameter d in the range 3.0 to 5.0mm, the sodium mole fraction x, in the range 0.63 - 0.8, and arc length ℓ are determined by interpolation or extrapolation on the graph of Figure 3 or by the equation

$$\ell = 4d + 11.76x + 0.25\,V - 16.4$$

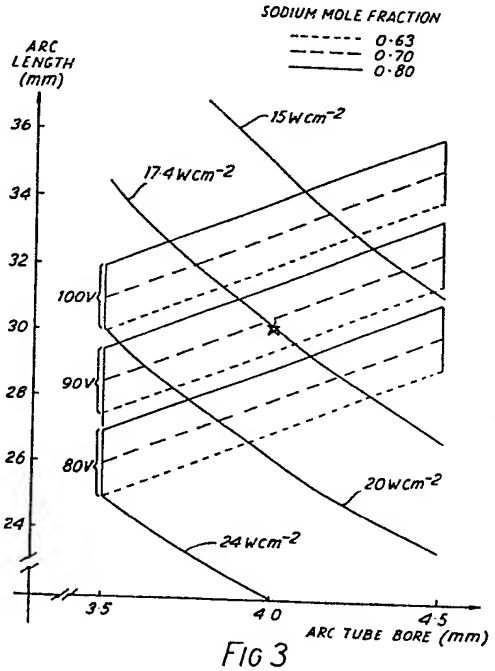

FIG 3

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IMPROVEMENTS IN OR RELATING TO HIGH PRESSURE SODIUM LAMPS

The present invention relates to high pressure sodium lamps which comprise a sealed discharge (arc) tube of a ceramic material, preferably polycrystalline alumina, in which a discharge takes place between electrodes at opposite ends thereof in a fill which includes sodium vapour in amalgam with mercury and an inert starting gas (usually Xenon at typically 20 torr cold fill pressure). The invention is particularly concerned with the optimisation of the arc tube bore and the arc length between the electrodes in relation to the sodium mole fraction of a sodium amalgam part of the fill to improve the efficacy of the lamp.

The high pressure sodium lamp (see "Lamps and Lighting" ed. Henderson & Marsden 2nd Ed. pp 242-249, Arnold) is now well established. It has been the subject of many investigations which have aided understanding of its physical properties and significant improvements in its luminous efficacy and the extension of the technology to lamps of progressively lower powers have resulted. The results of one such study are described and claimed in U.S. Patent No. 3 906 277 which provides certain criteria the satisfaction of which is said to result in a lamp of increased efficacy over the prior art.

Nevertheless it is believed that it is possible by suitable choice of the arc tube bore (internal diameter) and arc length (between the electrode tips), to improve the efficacy of lower

power high pressure sodium lamps and it is an object of this invention to provide a method of determining these dimensions with the aim of improving lamp design and to provide improved lower power lamps designed in such a manner. In particular it is an object to include lamps in power and voltage ranges not specifically included in the teachings of said U.S. Patent without extrapolation, for example a 70 watt, 70-130 volt lamp.

According to another aspect of the invention there is provided a high pressure sodium lamp for operation at a power rating of 70 watts and at a lamp voltage drop in the range 70 to 130 volts, the lamp including a substantially tubular light-transmitting arc tube whose internal diameter is in the range 3.0 to 5.0 mm, having thermionic electrodes sealed into the end thereof and filled with an inert starting gas and a sodium amalgam having a sodium mole fraction in the range 0.63-0.8, the arc length $\hat{l}$ in mm between the electrodes being defined substantially by the equation

$$\hat{l} = 4d + 11.76x + 0.25\ V - 16.4$$

where d is the arc tube internal diameter in mm, x is the sodium mole fraction, and V is the lamp voltage drop in volts.

According to one aspect of the invention there is provided a high pressure sodium lamp for operation at a power rating of 70 watts and at a lamp voltage in the range 80 to 100 volts, the lamp including: a substantially tubular light-transmitting arc tube whose internal diameter is in the range 3.5 to 4.5 mm, having thermionic electrodes sealed into the ends thereof and filled with an inert starting gas and a sodium and mercury amalgam having a sodium mole fraction in the range 0.63 - 0.8, the arc length between the electrode tips being determined substantially by the intersection of a line for a chosen arc tube bore with the line for a chosen lamp voltage and sodium mole fraction in Figure 3 of the accompanying drawings, or interpolation thereon.

Preferably the wall loading of the arc tube is restricted to less than 20 W/CM^2.

Preferably the cool spot temperature of the lamp is optimised by the adjustment of heat losses therefrom.

By a 70 watt lamp is meant a lamp of nominally 70 watt rating which is designed to run at 70 watts at a specified voltage although for various reasons the lamp may be run at different voltages at which the lamp power will not be 70 watts.

In order that the invention may be clearly understood and readily carried into effect it will now be described by way of example with reference to the accompanying drawings, of which,

Figure 1 is a graph indicating the effect of lamp voltage on efficacy for different arc tube bores,

Figure 2 is a graph indicating the effect of sodium mole fraction on efficacy,

Figure 3 is a graph defining the arc tube length required to optimise efficacy as a function of arc tube bore, lamp voltage and sodium mole fraction, and

Figure 4 shows a preferred 90 V high pressure sodium lamp in accordance with the invention.

The early high pressure sodium lamps in general use were 400 watt lamps. Subsequent developments have aimed at increasing the luminous efficacy of these lamps and also at providing efficient high pressure sodium lamps with lower power ratings such as the 70 watt lamp which this invention provides. In following this course attention has been paid to satisfying the three principle criteria which are long life, high efficacy and a good colour.

It is known that the efficacy of a high pressure sodium lamp, with its colour and life, depend on eleven variables. However, as discussed by P.L. Denbigh in "Lighting Research and Technology" (Vol. 10, No. 1 1978 pp 28-32) several of these are specified for economic and other considerations and others can be fixed, at least within known ranges during design work.

In the said paper by Denbigh an experimental design approach is explained, many of the considerations of which are valid now. However this paper did not consider the effects on

the lamp design of the amalgam ratio, which is known to affect the efficacy of the lamp both directly and indirectly.

The present invention therefore provides a 70 watt high pressure sodium lamp with a lamp voltage of 70-130V, which is known to be a preferred range, and taking certain criteria, which may be specified within ranges known to give increased efficacy, adjusts other criteria further to increase the efficacy.

For 70 watt lamps at this range of voltages constructed to give maximum efficiency (i.e. at optimum cool spot temperature) it has been found that efficacy increases as the tube bore decreases, as is shown in Figure 1, which is a plot of efficacy (in lumens/watt) against lamp voltage (in volts) for a 70 watt lamp for arc tubes with 4.0 mm and 5.3 mm bores. This plot is for a sodium mole fraction of 0.686 and for temperatures, at the cool spot at which excess amalgam collects, which are optimum for maximum efficiency. The optimum cool spot temperatures are obtained by using well known means (including heat screens, suitable construction and adjustment of electrode length) to adjust heat losses in the arc tube for operation at the specified voltage.

It has also been found that efficacy increases as sodium mole fraction decreases from 1 to 0.6 as shown in Figure 2, which is a plot of efficacy against sodium mole fraction between 0.8 and 0.6 for a 70 watt, 90V high pressure sodium lamp of 4 mm arc tube bore again at optimum cool spot temperature. It should be noted that as the sodium mole fraction approaches 0.6 the colour is exceedingly pink and is considered to be unacceptable for lighting purposes.

Taking the foregoing into account Figure 3 shows the dimensions required in accordance with this invention to achieve maximum efficacy for lamps adjusted using prior art techniques to be at their optimum cool spot temperature. The Figure shows the arc length, in mm, plotted as a function of the arc tube bore, in mm, for 70 watt high pressure sodium lamps intended to

operate at 80 volts, 90 volts and 100 volts. This is repeated for each of three sodium mole fraction values, 0.63, 0.70 and 0.80 defining a range which is considered to be satisfactory, particularly from the aspect of colour. Also illustrated for reference are lines of constant wall loading.

It has been seen from Figure 1 that for higher efficacy the bore must be as small as possible. At the same time constraints of wall loading, which for long life lamps is usually set at not greater than 20 W/Cm^2, and of arc tube size determine the smallest practicable tube bore. The arc tubes falling at the lower left hand corner of Figure 1 are on the limits of practical manufacture (evaporation of dose and arc tube cleanliness being the principal problems).

For lamps having sodium mole fractions between 0.63 and 0.80 and for voltages between 80 and 100V, dimensions may be obtained by interpolation in Figure 3 and dimensions for lamps outside these ranges may be obtained by extrapolation.

The use of the graph may be illustrated by the example of the preferred 70 watt 90 volt high pressure sodium lamp. Taking a satisfactory middle range sodium mole fraction of 0.688 it can be seen that this lamp should have an arc length of 30.2mm and an arc tube bore of 4.0 mm. The wall loading obtained is 17 .4 W/cm^2. The position of this lamp in Figure 3 has been indicated by a star and it is shown in the same manner in Figures 1 and 2.

The information conveyed by the graph of Figure 3 may be expressed in the form of an equation the application of which yields lamps within the ranges for which the invention applies, including those defined by that Figure.

Thus for a 70 watt high-pressure sodium lamp of voltage drop V between 70 and 130 volts having an arc tube dosed with a sodium amalgam with a sodium mole fraction x between 0.8 and 0.63 and an arc tube bore (internal diameter) d in the range 3.0 to 5.0 mm and having an optimum cool spot temperature by suitable adjustment of heat losses, the discharge may be caused

to operate at maximum efficacy by the choice of an arc length ℓ mm defined by:

$$\ell = 4d + 11.76\,x + 0.25V - 16.4$$

This equation is applied in the following examples.

EXAMPLE 1

For a 90 volt 70 watt high pressure sodium lamp

$$\ell = 6.1 + 4d + 11.76x$$

and for a preferred sodium mole fraction of 0.686 and arc tube bore of 4.0 mm the arc length required is 30.2 mm, which gives the preferred lamp indicated by the star on Figures 1-3.

EXAMPLE 2

For an 80 volt 70 watt high pressure sodium lamp

$$\ell = 3.6 + 4d + 11.76x$$

so that for a preferred sodium mole fraction of 0.686 and a preferred arc tube bore of 4.0 mm the arc length required is 27.7 mm.

EXAMPLE 3

For a 100 volt 70 watt high pressure sodium lamp

$$\ell = 8.6 + 4d + 11.76x$$

so that for a preferred sodium mole fraction of 0.686 and arc tube bore of 4.0 mm the arc length required is 32.7 mm.

These equations are believed to provide the arc length to within 0.15 mm, which is significantly within desirable production tolerances which are typically $\pm$ 0.5 mm. In manufacturing practice it is possible to provide arc tube bores to tight tolerances and the sodium mole fraction may be virtually exact. However it will be appreciated from study of the graph that small changes will not markedly affect the efficacy. It is therefore not intended that in determining the scope of the invention it should be limited to the precision with which the equations may be evaluated.

Figure 4 shows a preferred 70 watt 90 volt high pressure sodium lamp in accordance with this invention. A polycrystalline alumina discharge tube 1 has a length of 30.2 mm plus the two electrode lengths (in this example a total length

of 42 mm. The tube is of internal diameter 4.0 mm and has end caps 2 in which electrodes (not shown) and external leads 3 are mounted. The discharge tube is filled with a filling including Xenon starting gas at 20 torr cold fill pressure and a sodium amalgam with a sodium mole function of 0.686. The assembly is mounted in an outer envelope 4 being supported therein by a conventional metal framework 5. A conventional lamp base 6 is provided with a terminal 7.

The preferred 80 volt and 100 volt lamps are substantially the same apart from the dimensions of the arc tube which are about 10% shorter and 10% larger respectively.

What we claim is:

1. A high pressure sodium lamp for operation at a power rating of 70 watts and at a lamp voltage drop in the range 70 to 130 volts, the lamp including a substantially tubular light-transmitting arc tube whose internal diameter is in the range 3.0 to 5.0 mm, having thermionic electrodes sealed into the end thereof and filled with an inert starting gas and a sodium and mercury amalgam having a sodium mole fraction in the range 0.63-0.8, the arc length ℓ in mm between the electrodes being substantially defined by the equation

$$\ell = 4d + 11.76x + 0.25\ V - 16.4$$

where d is the arc tube internal diameter in mm, x is the sodium mole fraction, and V is the lamp voltage drop in volts.

2. A high pressure sodium lamp for operation at a power rating of 70 watts and at a lamp voltage in the range 80 to 100 volts, the lamp including: a substantially tubular light-transmitting arc tube whose internal diameter is in the range 3.5 to 4.5 mm, having thermionic electrodes sealed into the ends thereof and filled with an inert starting gas and a sodium amalgam having a sodium mole fraction in the range 0.63 - 0.8, the arc length between the electrode tips being determined substantially by the intersection of a line for a chosen arc tube bore with the line for a chosen lamp voltage and sodium mole fraction in Figure 3 of the accompanying drawings, or interpolation thereon.

3. A lamp according to either Claim 1 or Claim 2 in which the wall loading of the arc tube is restricted to less than 20 W/CM^2.

4. A lamp according to any of Claims 1 to 3 in which the sodium mole fraction is of the order of 0.7.

5. A lamp according to Claim 4 in which the sodium mole fraction is 0.686.

6. A lamp according to any of Claims 1 - 5 in which the arc tube bore is substantially 4.0mm.

7. A lamp according to any of Claims 4 - 6 being a 90 volt lamp in which the arc length is 30.2 ± 0.5mm.

8. A lamp according to any of Claims 4 - 6 being an 80 volt lamp in which the arc length is 27.7 ± 0.5mm.

9. A lamp according to any of Claims 4 - 6 being a 100 volt lamp in which the arc length is 32.7 ± 0.5mm.

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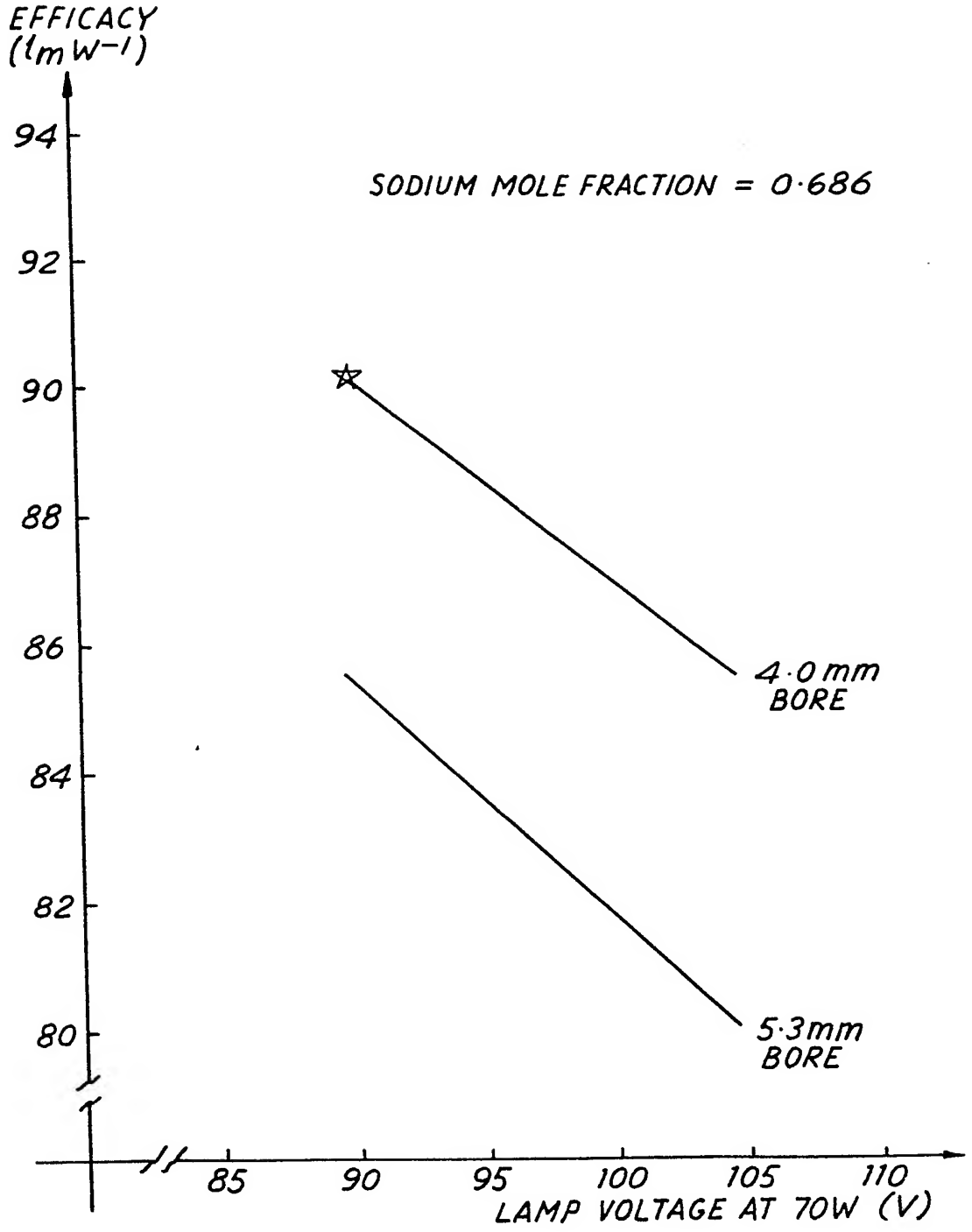
EFFICACY
(lm W-1)
94
92
90
88
86
84
82
80
SODIUM MOLE FRACTION = 0·686
4·0 mm
BORE
5·3mm
BORE
85
90
95
100
105
110
LAMP VOLTAGE AT 70W (V)

FIG. 1

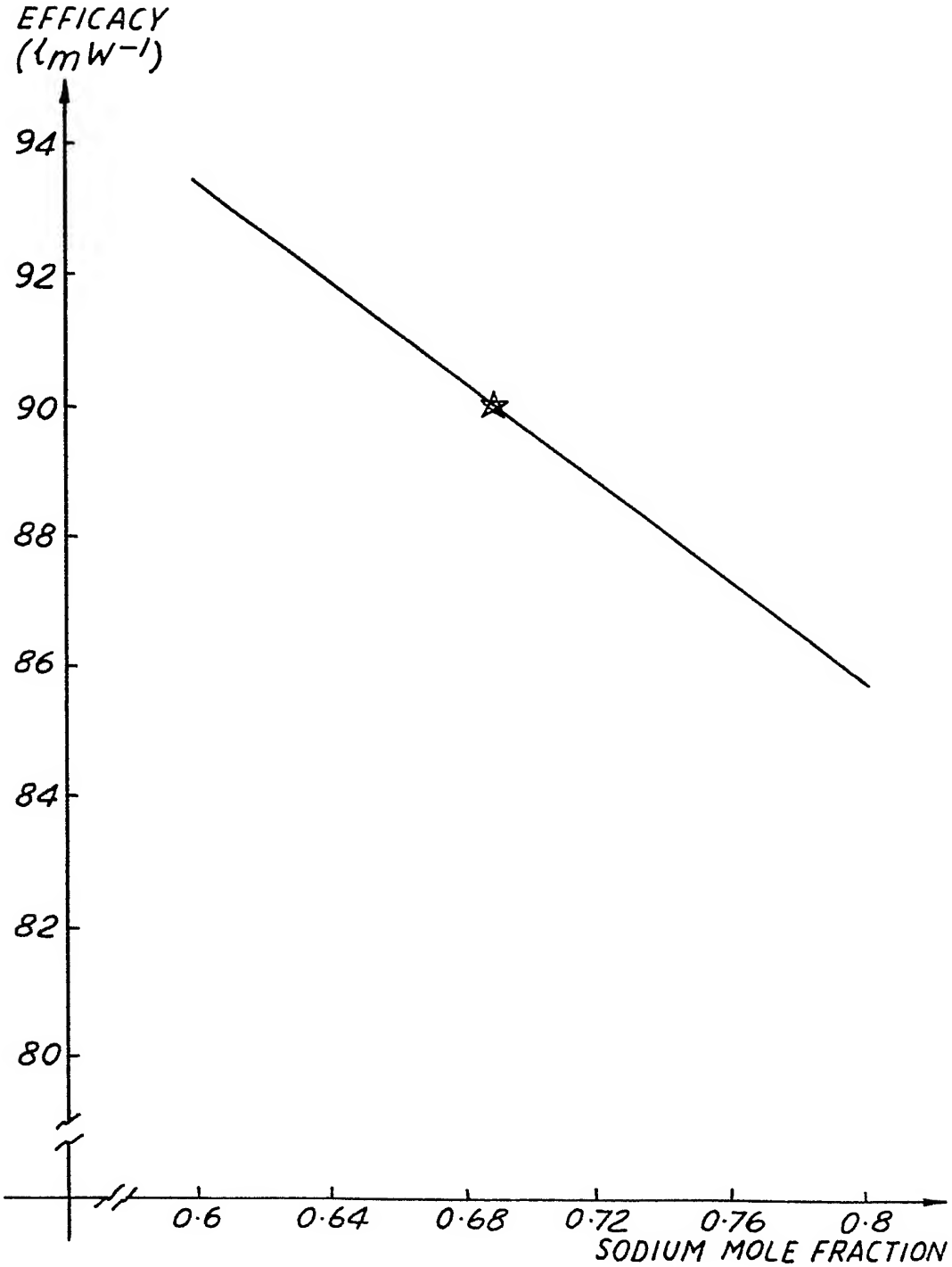
EFFICACY
(lmW⁻¹)
94
92
90
88
86
84
82
80
0·6
0·64
0·68
0·72
0·76
0·8
SODIUM MOLE FRACTION

FIG. 2

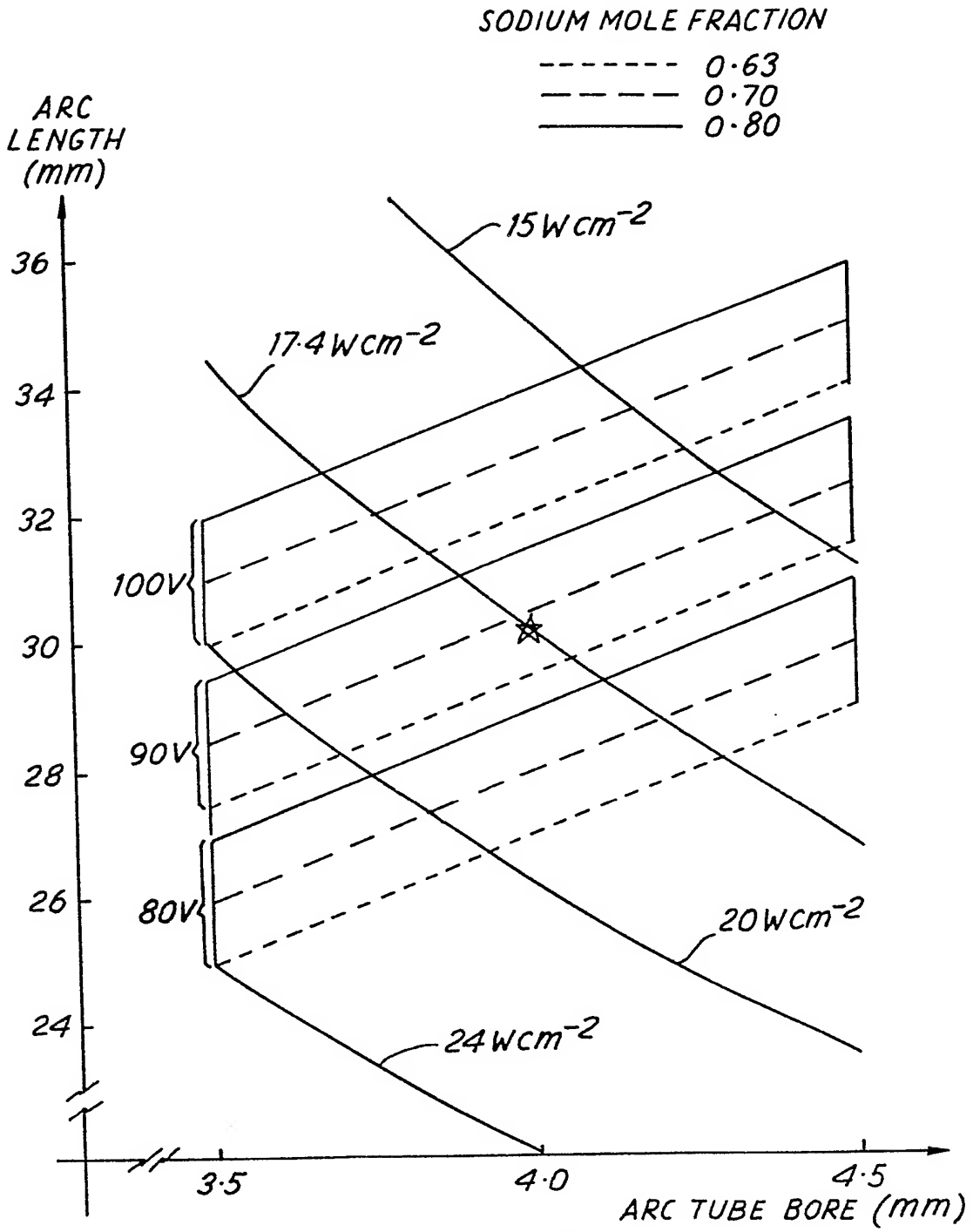
SODIUM MOLE FRACTION
0·63
0·70
0·80
ARC LENGTH (mm)
36
34
32
30
28
26
24
15 W cm⁻²
17·4 W cm⁻²
20 W cm⁻²
24 W cm⁻²
100V
90V
80V
3·5
4·0
4·5
ARC TUBE BORE (mm)

FIG.3

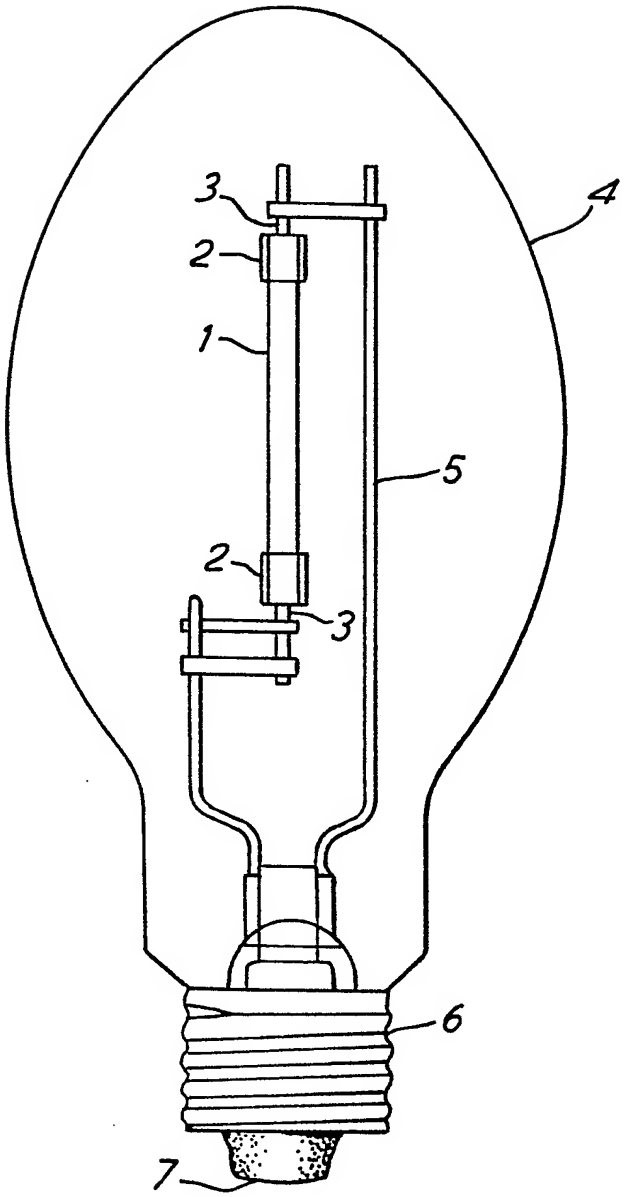

FIG. 4